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Variability in distortion product otoacoustic emissions among normal ears

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VARIABILITY IN DISTORTION PRODUCT OTOACOUSTIC EMISSIONS AMONG NORMAL EARS

Independent Study Project

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I. INTRODUCTION

Otoacoustic Emissions, which were first observed by Kemp (1978), have become widely recognized in recent years as an emerging clinical tool. Kemp Echoes, as they were first described, were originally thought to be the result of sound waves reflecting off of the external ear canal from an acoustic stimulus presented into the canal. Otoacoustic emissions are now known to be low-level signals generated within the cochlea. They can occur spontaneously, or they can be evoked (in response to an acoustic stimulus). Evoked emissions can be described as an assessment of the metabolic functioning of the outer hair cell independent of neural integrity (Popelka et al., 1995).

Otoacoustic emission measurements have proven to be a useful tool in the screening of neonates. The test itself requires very little time. Results are obtained by placing a probe tip (similar to the types used in tympanometry) into the ear canal. An acoustic stimulus is presented into the ear via one branch of the probe tube. The emission is then recorded via the other branch of the tube that has been inserted into the ear canal. Screenings can be done in as little as ten minutes, as opposed to the more invasive and time consuming ABR screening procedure. Emissions are generally thought to be present in all normal hearing ears, and absent with a hearing loss exceeding 30-50 dB HL.

II. TYPES

A. Spontaneous Otoacoustic Emissions

SOAE's, which occur in about fifty percent of humans (Burns, Arehart and Campbell, 1990), are basically continuous narrow-band signals which are present and can be recorded in the abscence of an acoustic stimulus. When first discovered, these emissions were thought to be a possible cause of tinnitus, but research has proven that no relationship exists between tinnitus and SOAE's (Katz,1994).

B. Transient or Click-Evoked Emissions

TEOAE's are responses recorded after a brief acoustic stimulus such as a click or a tone burst. They stimulate the cochlea over a wide frequency range and are therefore very useful clinically because they provide information about the entire cochlea. They are measurable in essentially all normal-hearing persons with normal middle ears and cochleas (Martin and Lonsbury-Martin 1986; Norton and Neely 1987). TEOAE's are primarily used clinically in infant hearing screenings.

C. Stimulus Frequency Emissions

SFOAE's are the most frequency specific and the least clinically applicable of all the emisssions types. A single, continuous puretone elicits a response within the cochlea occurring simultaneously and at the same frequency as the eliciting stimulus. This type of emission is considered more difficult to measure (Lonsbury-Martin, McCoy, Whitehead, and Martin,1992).

D. Distortion Product Otoacoustic Emissions

DPOAE's are considered the simplest type of emissions to measure. They can be elicited from essentially all normal ears, can be evoked over a relatively wide range of frequencies and typically have wide dynamic ranges. The distortion product is the result of two pure tones presented simultaneously (referred to as the primaries) into the ear canal. The most commonly used distortion product is called the cubic difference tone. This tone is the result of the two frequencies, F_1 and F_2 being presented externally. The difference tone produced within the cochlea, can be expressed as $2F_1$-F_2, as it occurs at a frequency equal to two times the lower frequency minus the higher frequency. This difference tone is a reflection of the non-linear metabolically active processes associated with outer hair cell functioning (Popelka et al., 1995). This is the distortion product recorded in humans.

The DPOAE measurements can be represented by a DP audiogram or "DPgram", or by an input/output function. The DPgram measures the amplitude of the DPOAE in response to a fixed intensity level at different frequencies ranging from 500-8000 Hz. The input/output function plots the amplitude growth of the DPOAE as the stimulus level increases. The stimulus frequencies (primaries) are geometrically centered around a specific frequency.

II. PURPOSE

The level of the distortion product for a single high-level stimulus (70 dB SPL) has been found to be a very poor predictor of hearing sensitivity. This is due to the fact that nonmonotonicities in the input/output functions may result in large fluctuations of the distortion product at a single level (Popelka et al., 1995).

The purpose of this study was to investigate the relationship between hearing sensitivity and the presence of OAE's, by examining the variability of same ear emissions in a group of normally hearing subjects. Three parameters of the distortion product input/output functions: slope, intercept and the area under the input/output functions are better correlated to hearing sensitivity than single-level distortion products. (Popelka et al., 1995). The test-retest variability of these parameters in normally hearing subjects influences the usefulness of the DPOAE input/output curve as a clinical tool.

III. METHODS

Six subjects, ranging from 23-28 years of age participated in the study on a volunteer basis. All subjects were graduate students at Central Institute for the Deaf, and were familiar with all testing methods prior to testing. Audiometric testing revealed hearing thresholds within normal limits. Tympanometry confirmed normal middle ear functioning for all subjects.

The Virtual, model 330 clinical otoacoustic emissions testing system was used for all measurements. Input/output functions were obtained at frequencies geometrically centered around 4000 Hz, and 6000 Hz, f_2 being 1.2 times higher than f_1. The levels of the primaries were increased in 5 dB steps and ranged from 30 -75 dB SPL. Noise floor measurements were plotted simultaneously with the DPOAE at $2f_1$-f_2. In order to lower the noise floor, signal averaging at 128 time frames per stimulus were used.

Three out of six subjects were instructed to remove the probe tip after each presentation, after which it was replaced by the tester for the following presentation. The remaining three subjects were instructed to leave the stimulus probe in their ears for the duration of testing. Five input/output measures were taken at each frequency. All subjects were instructed to remain quiet throughout the testing procedure. Three measures were derived from the resulting I/O functions. Only emissions that were at least 5 dB above the noise floor were included in the data. The first measure is the slope or growth of the input in dB/output in dB. The second measure is intercept, where the average level of the noise floor intersects the DPE. The third measure is the area under the I/O function, or the area between the average noise floor and the highest emission level (in dB squared).

IV. RESULTS

The test/retest functions resulted in variability across parameters, both within subjects and between subjects. The average slope for all six subjects was .9 at 4000 Hz, and .875 at 6000 Hz (Figure 1). The average intercept was 45.9 at 4000 Hz, and 34 at 6000 Hz.(Figure 2). For area, the inter-subject averages were 321 and 645 for 4000 Hz and 6000 Hz, respectively (Figure 3). Within subject standard deviations for the slope were within .199 and .237 at 4000 Hz and 6000 Hz respectively. Between subject standard deviations were .335 and .19

at 4000 Hz and 6000 Hz respectively (Figure 4). For intercept, the standard deviations were 7.6 at 4000 Hz, and 12.2 at 6000 Hz within subjects. Between subjects the standard deviations were 12.2 and 2.3 at 4000 Hz and 6000 Hz respectively (Figure 5). Finally, the standard deviations for area were 104 at 4000 Hz, and 254 at 6000 Hz within subjects. Between subjects, the standard deviations were 170 at 4000 Hz, and 130 at 6000 Hz (Figure 6).

The average slope across the two frequency regions was .888. Between subjects, the standard deviation was .335 at 4000 Hz, and .167 at 6000 Hz. Within subject average standard deviation for area was 179. Between subjects this average was 150. The standard deviations for intercept within subject average was 9.9. The between subject average standard deviation for intercept was 13.35.

Overall, the best reliability between subjects and within subjects across the two frequency regions proved to be the slope of the function. The area was the least reliable parameter in terms of test/retest reliability within the same subjects, or when comparing inter-subject data. This is due to the fact that there are two sources of variance for area; the increase in slope, and the average level of the noise floor. This also accounts for the large variability between frequencies. The average noise floor at 4000 Hz was -16 dB, and at 6000 Hz was -25.5 dB. Thus, the largest standard deviation occurs with area, especially when comparing the two frequency regions.

V. CONCLUSION

The use of an input/output function for low-level signals has been found to reduce the possibility of contamination from non-linearities not associated with the outer hair cell system. (Popelka et al., 1995) Although some consistency has been reported in human data concerning the input/output functions (Gaskill & Brown, 1990 ; Lasky et. al., 1992), this study failed to produce highly reliable test/retest data. Reproducible measures were made with the variable of probe replacement (Gaskill & Brown, 1990), and Lasky et. al.(1992) have reported impressive within and between session reproducilbility for a small number of subjects.

This study found linear, nonlinear and nonmonotonic functions for individuals independent of probe replacement. This study, along with previous studies, tried to fit the data (primarily curves) with linear functions. This may contribute to the variability seen both within subjects and between subjects. This nonlinearity could be due to a number of factors such as variability in the noise floor, including subject noise.

Although there were measurable distortion products above 50 dB for almost all of the functions, the variability between and within subjects for all three parameters of the functions leaves much room for question regarding the correlation of the input/output function to hearing sensitivity. The relatively large standard deviation between subjects indicates that normative values are not well-defined. The within subject variability shows that the same subject could display results within normal limits for one test, followed by questionable or even abnormal results within same-session testing.

Although the rate of growth for a typical input/output function for stimuli above 50 dB is likely to be 1 dB/ dB of stimulus level, below this level sharp discontinuities or notches can occur. There are many theories as to why these nonlinearities may occur. Moulin et al.(1992) have suggested that the presence of a spontaneous otoacoustic emission may be associated with a drop in the level of the emission at certain frequncies. This remains to be seen, as further study may reveal the true nature of the metabolic processes associated with such variabilities.

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FIGURE 1: Average slope of input/output function for six normally hearing subjects

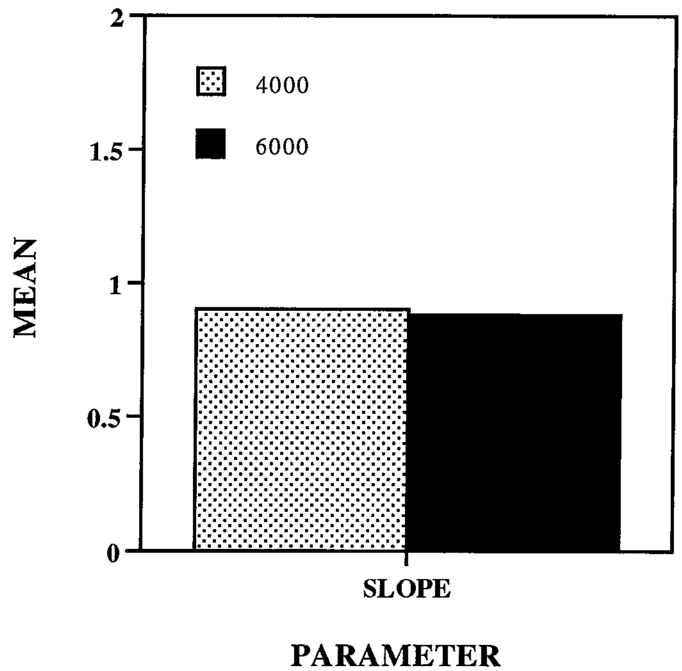

FIGURE 2: Average intercept of input/output function and noise floor for six normally hearing subjects.

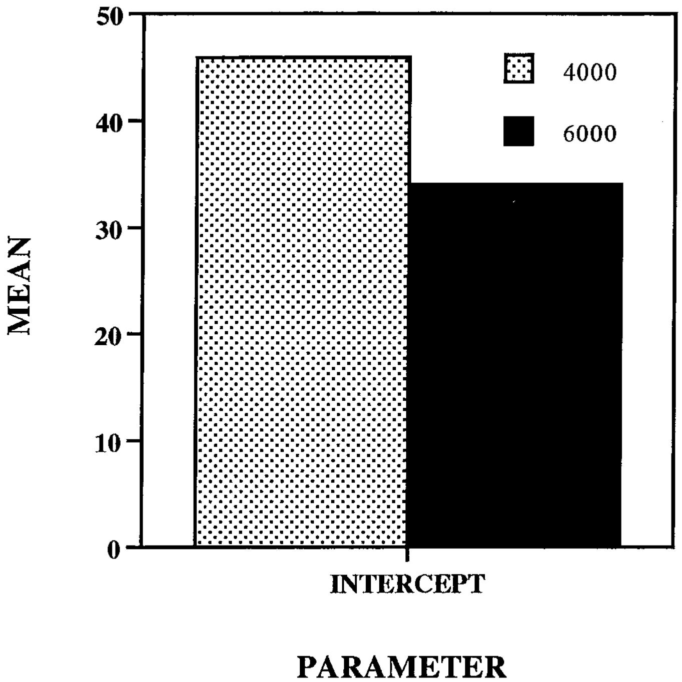

FIGURE 3: Average area under the input/output curve for six normally hearing subjects.

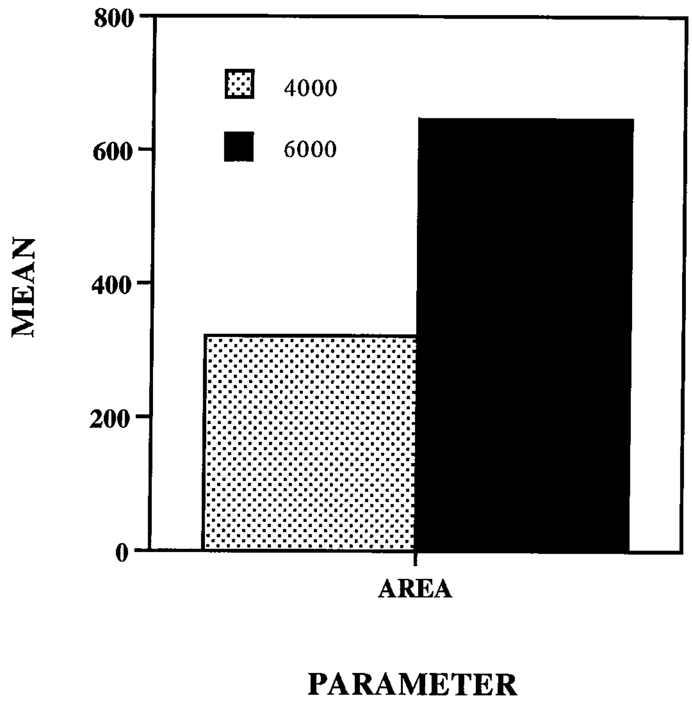

FIGURE 4: Within and between subject standard deviations for normally hearing subjects. The parameter is the slope of the input/output function.

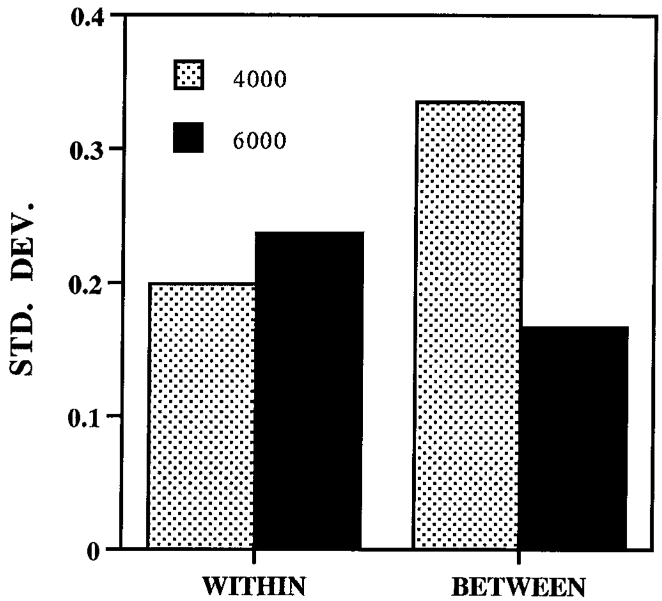

Figure 5: Within and between subject standard deviations for normally hearing subjects. The parameter is the intercept of the input/output function.

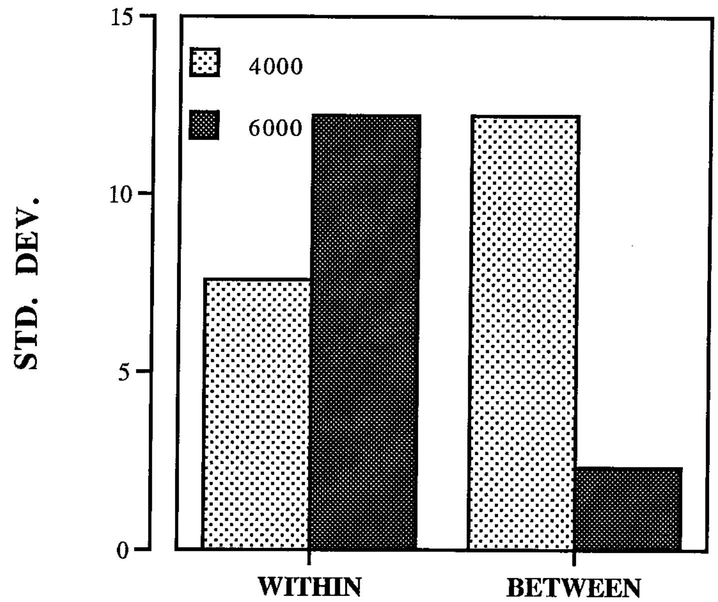

FIGURE 6: Within and between subject standard deviations for normally hearing subjects. The parameter is the area under input/output function